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Worldwide potential for ex-situ mineral carbonation

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Abstract

World data on (i) CO_2-emission sites and (ii) ore deposits in mafic/ultramafic (M/UM) rock contexts have been crossed through a GIS (under ArcGIS) in order to identify sites of potential interest for implementing the ex-situ carbonation method. Applying relevant criteria, such as the nature and quantity of mining waste, volumes of CO_2 emission, distance between mine and emission sites, and adding mining data from the literature, has led to a selection of eight potential ore deposits in an ultramafic rock context. These are located in Botswana, South Africa, China, Russia and Kazakhstan, and all lie within a 300 km radius of coal-fired industrial plants emitting >1Mt/year CO_2. This approach is but a first level of reflective thinking that could be complemented by applying hydrographic, topographic, chemical and mineralogical, economic, and even political criteria.

Keywords: GIS, mineral carbonation, CO_2, mafic and ultramafic rocks

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1. Introduction

The geological storage of CO2, in particular by injection into depleted oil and gas reservoirs and saline aquifers, is presented as the solution for storing the massive industrial emission of CO2 throughout the world. Mineral carbonation, which involves trapping CO2 by chemical reaction with suitable mineral phases to form stable inert carbonates, can be considered as an alternative, longer term, technique and as a local "niche" option.

The Carmex research project, at present being carried out by a French multidisciplinary consortium, is attempting to assess the potential for ex-situ mineral carbonation (in terms of mineral resources, carbonation processes and mechanisms, life cycle analyses, etc.) in favourable contexts. In particular, the material to be carbonated must be abundant, fine grained and rich in ferromagnesian and/or calcic minerals. For example, the reaction for olivine is written:

$$Mg_2SiO_4 + 2CO_2 \rightarrow 2MgCO_3 + SiO_2 \ (+90 \text{ kJ/mol } CO_2).$$

One potentially 'carbonatable' material in terms of both quantity and quality is the waste from mining world-class ore deposits related to ultramafic (UM) and mafic (M) rocks. Quantity-wise, very large volumes of carbonatable material are required, since 4 to 6 tons of material are necessary to fix 1 ton of CO_2 [1]. Quality-wise,

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ultramafic rocks are very low in silica (<45% by weight) and rich in Fe, Mg, Ca (>40% by weight), whilst mafic rocks are low in silica (between 45 and 52% by weight) and contain Na, K, Mg and Ca (30 to 40% by weight).

This article summarizes the results obtained from crossing of two data sources – (i) the world inventory of "Large and Superlarge Deposits" and (ii) CO2-emission sites – using a GIS under ArcGIS. The objective is to rank sites of interest for implementing the ex-situ mineral carbonation method.

2. Methodology and results

2.1. The approach

The study was broken down into three successive steps, as summarized on the flow chart of Figure 1. The first step was to access georeferenced databases, extract the mine sites corresponding to selected petrographic criteria, and then cross these under ArcGIS with world data on CO_2 emission sites. Additional criteria were then selected and applied so as to arrive at a smaller selection of the most favourable sites (steps 2 and 3).

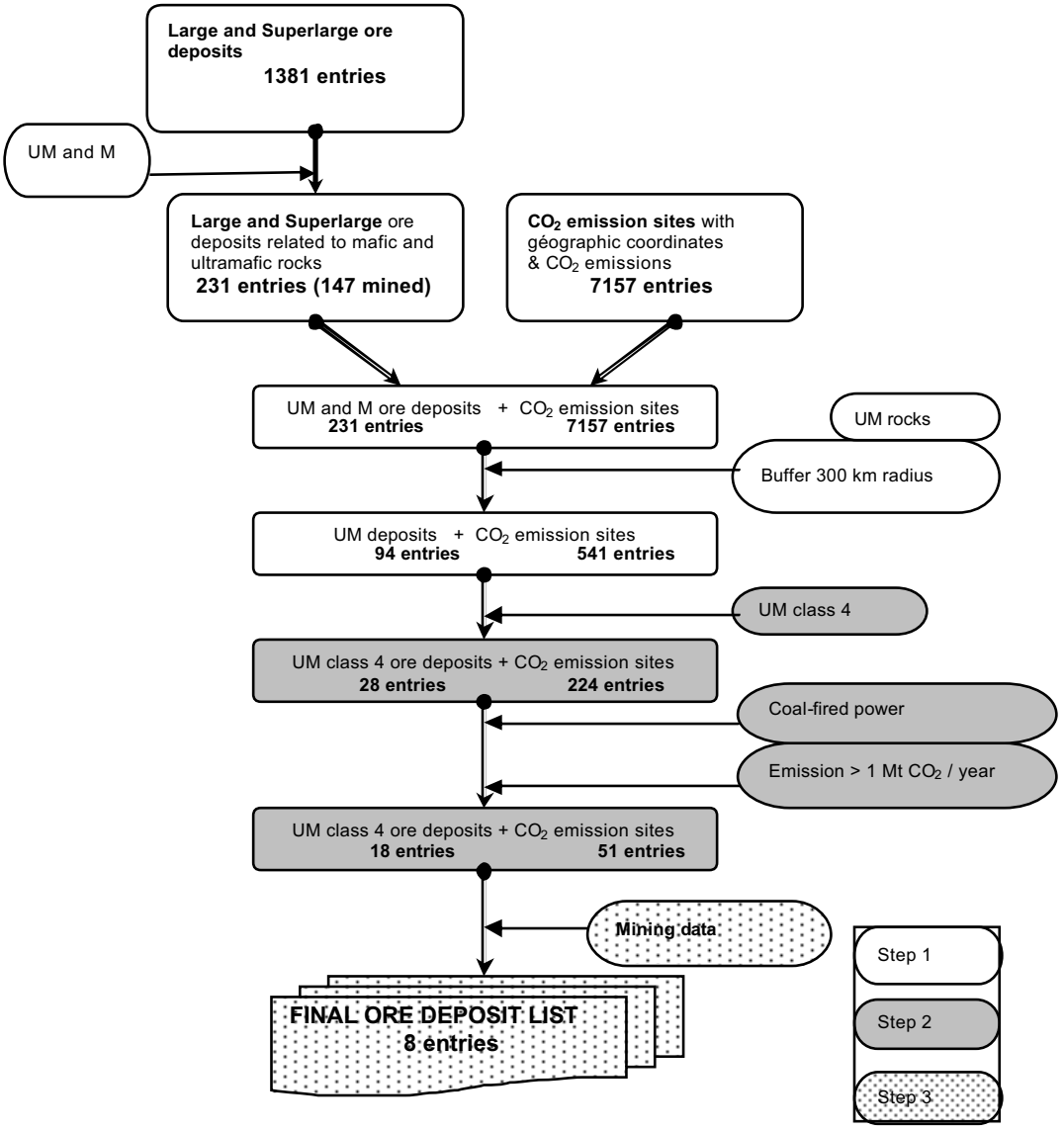

Figure 1: Data processing flow chart.

2.2. Data input

The inventory of CO_2-emission sites was made from the IEA 2006 global emissions database [3] by selecting the georeferenced sites with known quantities of CO_2 emission; i.e. 7157 records of sites that are operational, under construction or planned. The total quantity of CO_2 emitted by these sites represents 12 billion tons, ranging from 2.85 kt to 44.1 Mt/year.

At the same time, based on the available lithological descriptions, ore deposits related to a mafic and/or ultramafic context were selected from the 2006 "Large and Superlarge Deposits" database of the Russian–French Metallogenic Laboratory [2], which contains 1381 entries. Of the 231 deposits that were selected, 147 are being mined or under development and are capable of generating large volumes of potentially carbonatable ore-processing tailings (between 100 million and several billion tons per deposit, for the largest).

The combined locations of the "CO_2-emission sites" and the "UM and M Ore Deposits" from the two thematic ArcGIS layers constructed from the inventories are shown in Figure 2.

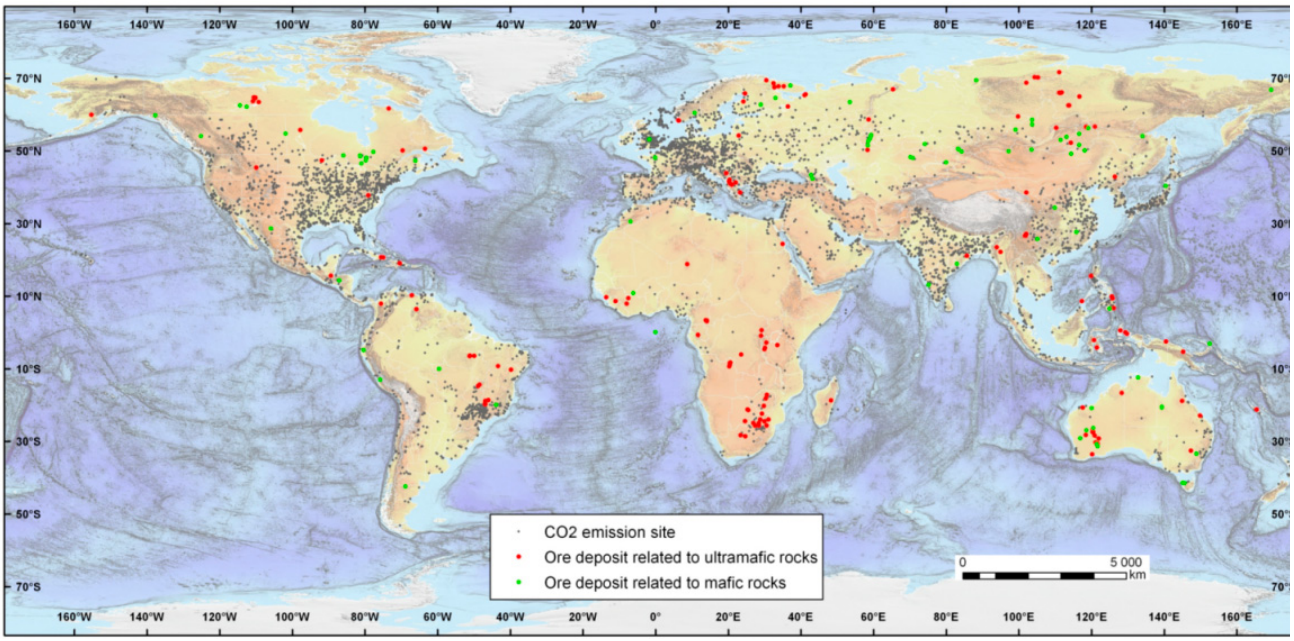

Figure 2: Geographical distribution of the CO_2-emission sites and ore deposits related to ultramafic and mafic rocks.

2.3. Additional selection criteria

2.3.1. Selection of the ultramafic ore deposits

Ore deposits related to an ultramafic rock context, which are the most favourable for the ex-situ mineral carbonation method, were selected at this stage. The ores from these deposits (i.e. nickel, copper, chromium, PGE) are generally disseminated in the ultramafic rock and their extraction generates ore-processing tailings that are rich in Mg- and Ca-bearing minerals with a fine grain size distribution due to the grinding prior to processing; this mining waste thus responds well to the criteria retained for carbonation.

Conversely, ore deposits associated with a mafic rock context do not systematically generate waste suitable for carbonation. The ore-processing tailings have a good grain size distribution, but are poor in Mg and Ca, whilst the barren waste is rich in Mg and Ca and would be potentially carbonatable after significant grinding.

2.3.2. Distance criterion

The distance criterion was then considered using increasing radius buffers (0-5, 0-10, 0-20, 0-30, 0-40, 0-50, 0-100, 0-300 km). For transporting the CO_2, the most appropriate solution for distances up to 300 km would appear to be a pipeline (results from the Carmex project partners: Bio Intelligence Service S.A.S. and Total).

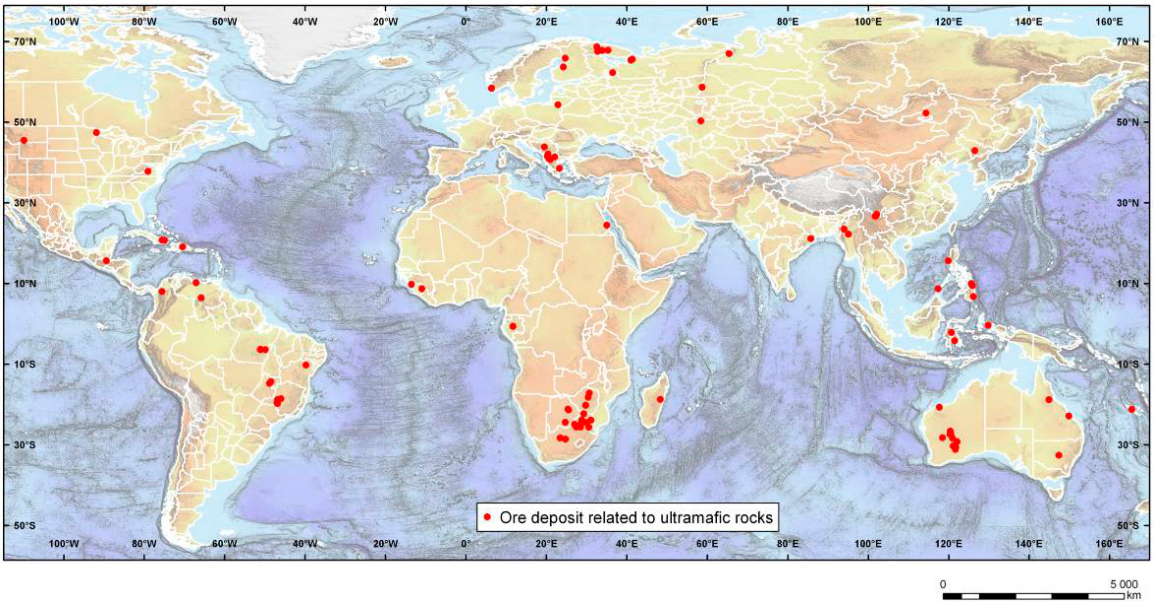

Figure 3: Ore deposits related to ultramafic rocks lying less than 300 km from a CO_2-emission site.

Crossing the two GIS layers revealed 94 ore deposits related to ultramafic rock in spatial relationship with 541 CO2-emission sites within a radius of 300 km (Fig. 3). Their geographical distribution reveals the presence of clusters rather than a homogeneous distribution over globe's surface; this is particularly the case in South Africa, the Kola Peninsula, Western Australia, Brazil (Minas Gerais, Goias), Greece and Macedonia.

At this stage of the investigation, the situation of the South African sites would appear to be completely favourable (Fig. 4); i.e. a concentration of ore deposits related to ultramafic rocks, very large amounts of mining waste (several billion tons) and many CO2-emission sites. Conversely, there appears to be very little of possibility of ex-situ storage in the United States, which is one of the main CO2 producing countries.

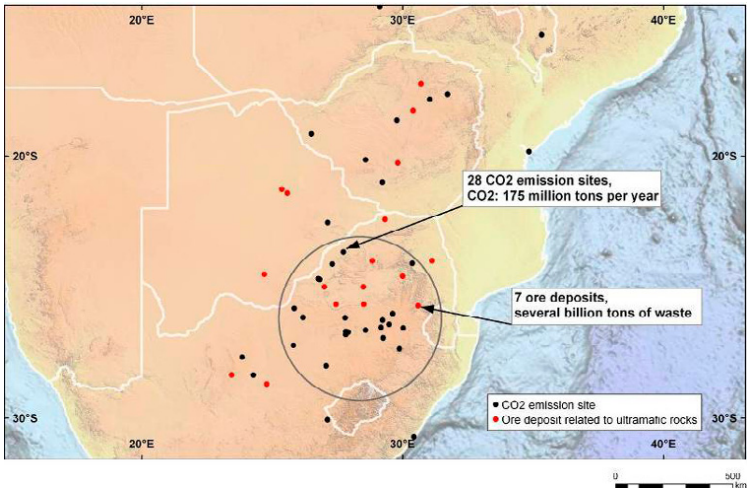

Figure 4: South Africa - example of a favourable sector (adopted radius of 300 km).

2.4. Refinement of the selection criteria (Step 2)

Further criteria were imposed for both the CO_2-emission sites and the ore deposits. For the former, only the major sites fired by coal and emitting more than one million tons of CO_2 per annum were selected. The reason for this is that, for optimal effectiveness, the current most widespread process for the amine capture of CO_2 needs to be implemented at coal-fired power stations where the smoke has the highest CO_2 concentration (12-15%). The most effective devices enable 3000 t CO_2/day to be treated, which is approximately 1 Mt CO_2/year.

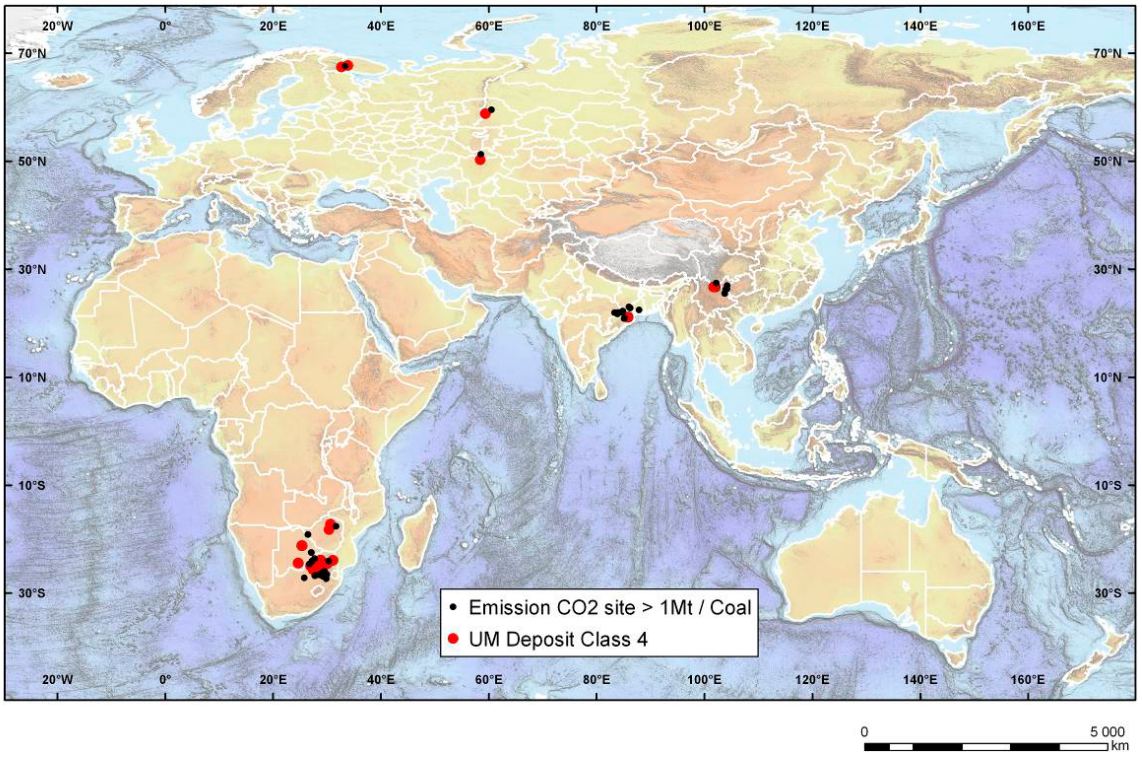

Figure 5: Coal-fired sites emitting >1 Mt/y CO_2 and located less than 300 km from a 'Superlarge' ore deposit related to ultramafic rocks.

Then, considering the mass of waste necessary to fix 1 ton of CO_2, the selection criteria limited the ore deposits related to ultramafic rocks to "Superlarge" (those of Class 4), which are likely to offer the greatest quantities of waste suitable for the carbonation process. These two additional criteria resulted in the selection list being reduced to 18 Class 4 ore deposits related to ultramafic rocks showing a spatial relationship with 51 CO_2-emission sites within a radius of 300 km (Fig. 5).

2.5. Introduction of mining data (Step 3)

The last step of this study consisted in informing the 18 selected ore deposits with data from the literature and mining databases [4], [5], [6], [7], [8] and [9]. The data search primarily involved technical and economic aspects of the mining, such as the type of mining, duration of the operation, production data, ore-bearing rock, ore-processing method, and data on the generated waste.

Regardless of the consulted source, it is very difficult to obtain information on the potential quantity of generated mining waste; only orders of magnitude are available. Introducing the mining data left a list of 8 ore deposits whose characteristics meet all the proposed criteria (Table 1).

Table 1: Characteristics of the 8 selected ore deposits and spatially associated CO_2-emission sites.

Superlarge (class 4) UM ore deposits				CO_2 emission sites within 300 km					
Name	**Country**	**Main commodity**	**Rocks**	**Distances (km)**	**CO_2 sites**	**Country**	**Total CO_2 kt/year**	**Main fuel**	**Estimated volume of waste**
Jwaneng	Botswana	diamond	sandstone, shale, basalt, kimberlite, gneiss, granite	231 - 293	2	South Africa	7 500	coal	~ 250 Mt
Orapa	Botswana	diamond	shale, sandstone, conglomerate, calcrete, silcrete, kimberlite	248 - 279	1 2	Botswana Zimbabwe	7 700	coal	~ 350 Mt
Panzhihua	China	Fe	limestone, gabbro, peridotite, dunite, anorthosite, syenite	108 - 290	6 1	China India	50 000	coal	> 100 Mt
Kempirsai	Kazakhstan	Cr_2O_3	harzburgite, chromitite, serpentinite, dunite, gabbro, schist	175	1	Russia	1 179	coal	100 Mt
Kachkanarskoye	Russia	Fe, V_2O_5, TiO_2, PGE	pyroxenite, hornblendite, gabbro, plagioclasite, schist, amphibolite	197	1	Russia	2 439	coal	> 10 Bt
Premier	South Africa	diamond	kimberlite, quartzite, sandstone, felsite, norite, gabbro	108 - 282	1 4	South Africa	130 000	coal	> 1 Bt
Bushveld Nor	South Africa	Cr_2O_3	magnetitite, pyroxenite, diorite, anorthosite, norite, chromitite,	130 - 281	6 1	South Africa Botswana	57 000	coal	> 1 Bt
Phalaborwa	South Africa	P_2O_5	pyroxenite, sovite, foskorite, glimmerite, granite, gneiss, regolith	85 - 299	2	South Africa	12 000	coal	> 1 Bt

3. Discussion - Conclusion

This article discusses a search methodology for sites potentially capable of supplying the materials necessary for implementing ex-situ mineral carbonation near very large emissions of CO_2. A limited selection of 8 ore deposits related to an ultramafic-rock context is proposed. The ore deposits are located at <300 km from coal-fired industrial facilities emitting >1Mt/y CO_2. They are located in Botswana, China, South Africa, Russia and Kazakhstan. World distribution maps of the sites are provided for each step of the process.

It should be noted that use of the waste from the diamond mines (3 sites) is not in fact possible because of current or planned retreatment projects by the operating mining companies.

Topographic realities should also be taken into account. For example, preliminary estimations were made for two sites -- the Panzhihua ore deposit (UM-9558) in China and the Venetia ore deposit (UM-416) in South Africa -- by applying a 500-m-grid digital elevation model (the USGS DEM - GTOPO30) under ArcGIS and calculating the average slopes. This showed the former to be in a very hilly environment with average slopes of 12 to 33%, and the latter to be relatively flat very with slopes of <3%.

Finally, consideration should be given to an experimental assessment of the nature of the waste and accelerated carbonation tests so as to be able to estimate the actual carbonation potential of the material and the cost of the operation.

In conclusion, the proposed approach represents a first level of reflective thinking which has made it possible to identify mining operations that are potentially very favourable for applying the ex-situ CO_2 carbonation method, and that lie within 300 km of major CO_2-emission sites. It nevertheless appears that, on considering the retained criteria,

very few of these ore deposits are finally accessible. It would thus be interesting to continue the approach by integrating other factors, such as the chemical and mineralogical composition of the mining waste, the mechanical and chemical processing to which the ore was subjected, and also topographic and hydrographic criteria on a broader selection of ore deposits (i.e. not only the "Superlarge" deposits).

Acknowledgments

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